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COMPRESSIVE PROPERTIES OF BUILT-UP COLUMNS

Progress Report - May 1956

PRELIMINARY REPORT

ON WELDED AND RIVETED MEMBERS

by

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This work has been carried out as part of an investigation sponsored jointly by the Column Research Council, the Pennsylvania Department of Highways and Bureau of Public Roads, and the National Science Foundation

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TABLE OF CONTENTS

This report is a preliminary description of the results obtained to date on pilot tests on built-up columns (riveted and welded columns). This work is "Part III" of Column Research Council Project 33A, RESIDUAL STRESS AND THE COMPRESSIVE PROPERTIES OF STEEL (see table attached). The remaining parts of the program are under way. The results obtained up to date will now be described. Some coupons and cross sections, several residual stress measurements, and one welded column were tested.

I. RESIDUAL STRESSES IN RIVETED AND WELDED MEMBER

1. Residual Stresses Prior to Fabrication - In order to know how much residual stress is present in the original plates and angles to be fabricated, plain plates and angles were measured by the sectioning method previously reported. Fig. 1 shows the results of these measurements. The magnitude of stresses was approximately 5 to 10 ksi, which depended on the thickness and width of plate and, of course, there was compression stress in tip and tensile stress in center of plate.

The second from the top in Fig. 1 shows how flame-cutting affects residual stress distribution and magnitude. As would be expected, large tensile stresses exist at the plate edges (approximately 30 ksi).

2. Residual Stresses After Fabrication - Residual stress distribution and its magnitude in welded specimens should be a function of plate dimensions and welding conditions (welding speed, energy of source, condition of restraint, etc.)

The typical procedure used in a fabricating shop was selected for making the welded specimens.

Figure 2 shows a typical result and a comparison with a rolled section. The solid line in Fig. 2 shows the final pattern after complete sectioning, whereas the dotted line shows the results after partial longitudinal sectioning. The average maximum compressive stress is approximately 21 ksi at the tip of the flange, and 35 ksi at the flange center (near yield point stress). At the web center was a compressive stress of 13 ksi.

Under the influence of welding process, one flange has a larger value (24 ksi) than the other (17 ksi) because the latter flange was welded first.

In welded specimens, the change of residual stresses at intersection of flange and web is very rapid, therefore exact distribution and magnitude are not obtained by this method. However, we are primarily concerned with the compressive residuals, and in this sense the sectioning method is still sufficiently accurate. The tensile stresses may be approximately determined by considering of equilibrium over the whole section.

These compressive stresses (flange edges of welded specimens) are higher than those found on the average in rolled members. It is probably due to the fact that cooling stresses were already present in the unwelded plates (Fig. 1, top) of about 8 ksi, and the welding simply increased this value.

In Fig. 3 is shown a comparison between an "average" rolled member, the unwelded plates, and the welded column.

II. CROSS-SECTION TESTS AND COUPON TESTS

1. Coupon Data - All specimens were taken from original plates and angles which were located adjacent to the cross section specimen. Coupons were tensioned in the sixty-kip hydraulic machine with very slow strain rates. As can be seen from Fig. 4, the plastic range of the material to be welded was rather smaller ($\frac{\varepsilon_{st}}{\varepsilon_y} \cong 5$) than the usual ratio of about ten to twenty.

Idealized average curves are drawn in Fig. 4.

2. Cross-Section Test (Short Column Test $L/r \cong 7$) - The test setups and procedures are the same as before. Two welded and one riveted 30-in. length short columns were compressed concentrically in an 800-kip screw-type machine, and the average strains were measured over a 10-in. gage length at the middle of the column. Alignment was done by using two sets of circular wedges at both ends of the member, the measurements of shortening at four corners were done as a check of uniform loading during tests.

Since mechanical $\sigma-\varepsilon$ curve and $\sigma-\varepsilon$ curve made from SR-4 readings showed a good agreement, mechanical $\sigma-\varepsilon$ curves were used to calculate the column curves.

Figure 5 shows, at the top, the welded cross-section test compared with weighted coupons, and at the bottom, the riveted cross-section with its coupons.

The most significant feature in these tests is the difference in column curves between riveted and welded column. (See Fig. 5). Riveted $\sigma-\varepsilon$ curve has a flat portion corresponding approximately to the yield level in coupon tests. However, the welded $\sigma - \varepsilon$ curve has no flat portion at all.

The main reasons which cause the early divergence from the elastic line in the welded member, and no flat yielding, are that the welded column has a considerable amount of residual stresses and different material properties within the cross section.

That is to say, the compressive residuals (up to 24 ksi) cause very early divergence from the elastic line and the different material properties due to welding results in no "flat yielding".

Actually, the part of the specimen which includes deposited metal can have fifty per cent higher yield stress than the original material and has almost no flat portion of yielding. This fact, and high tensile residuals, and also the small $\varepsilon_{st}/\varepsilon_y$ ratio (mentioned before) account for the lack of a yield "level". As a matter of fact, the tip of the flange may enter the strain-hardening range at $\varepsilon = 5 \times 10^{-3}$. To certify this, several coupons taken from different positions of the welded shape are under way.

3. <u>Column Curves</u> - The σ/σ_y - E_t/E relationship (Fig.6) taken from cross-section $\sigma - \varepsilon$ curve, can offer a non-dimensional tangent modulus curve in the usual manner. Note the large difference between welded and riveted specimens.

To get a true column curve for strong and weak axis, we have to know the distribution of residual stress over the cross section. Fortunately in this case, up to $\sigma/\sigma_y = 0.579$

(see Fig.7), the web will not be yielded because of smaller compressive residual stresses. Therefore column curves for both axes are easily obtained by the methods described in previous progress reports from data taken from a cross section test. Also, column curves which are based on residual stress measurements were calculated by a step-by-step method.

The "strong axis" curves are shown in Fig. 7. The "weak axis" curves are shown in Fig. 8, along with the test results. The riveted curve is higher than the welded ones (Fig.7). For the strong axis, the three methods of predicting the welded column curves agree reasonably well.

Concerning the weak axis (Fig.8) there is fair agreement with the two curves for the welded specimen. The test result is above both curves. The approximate column curve for rolled shapes with residual stress is considerably higher than for these particular welded specimens (Fig.8).

III. COLUMN TEST

Up to the present, only one column (T-6, the short welded column) has been tested in weak axis. The load which was carried by the specimen (389 kips, see Fig.9) exceeded the load calculated by cross-section data (323 kips) by twenty per cent.

However, as can be seen in Fig. 9 (enlarged scale), the load-deflection curve deviates more rapidly from the load-axis at the "tangent modulus" load, even though the absolute value of deflection is very small. This shows the fact that at the "tangent modulus" load, the column will start to bend.

Actually, as SR-4 readings show, the flange was unloaded at approximately 350 kips. This means that the maximum load-carrying capacity should be higher than the tangent modulus load, especially in the case of welded columns which have a stress-strain curve that is continually rising. Therefore the buckling load may approach the reduced modulus load.

IV. SUMMARY

1. Residual stresses in these Universal Plates at the flange tips, were about 5 to 10 ksi in compression.

2. The welded H-section had approximately 21 ksi and 13 ksi compressive residual stresses at flange tip and at center of web, respectively. The pattern is about a hyperbola in the flange, and a circle in the web.

3. The welded cross section started to yield at $\sigma/\sigma_y = 0.38$, and the riveted specimen yielded at $\sigma/\sigma_y=0.63$. The welded specimen has no flat yielding portion.

4. A large reduction of column strength was observed in the case of a welded column specimen (at $L/r=80$, $\sigma_{cr}/\sigma_y = 0.50$ in weak axis).

5. It is shown that for the strong axis, the tangent modulus curve is a satisfactory approximation.

6. For the weak axis, present theories are conservative insofar as the welded specimens are concerned.

V. ACKNOWLEDGMENTS

This work has been carried out at Fritz Engineering Laboratory, of which Professor William J. Eney is Director.

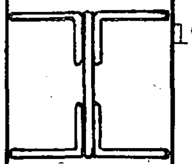
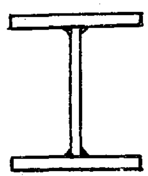
The author wishes to express his appreciation to the Sponsors of this program, namely, the Column Research Council, the Pennsylvania Department of Highways and the Bureau of Public Roads, and the National Science Foundation.

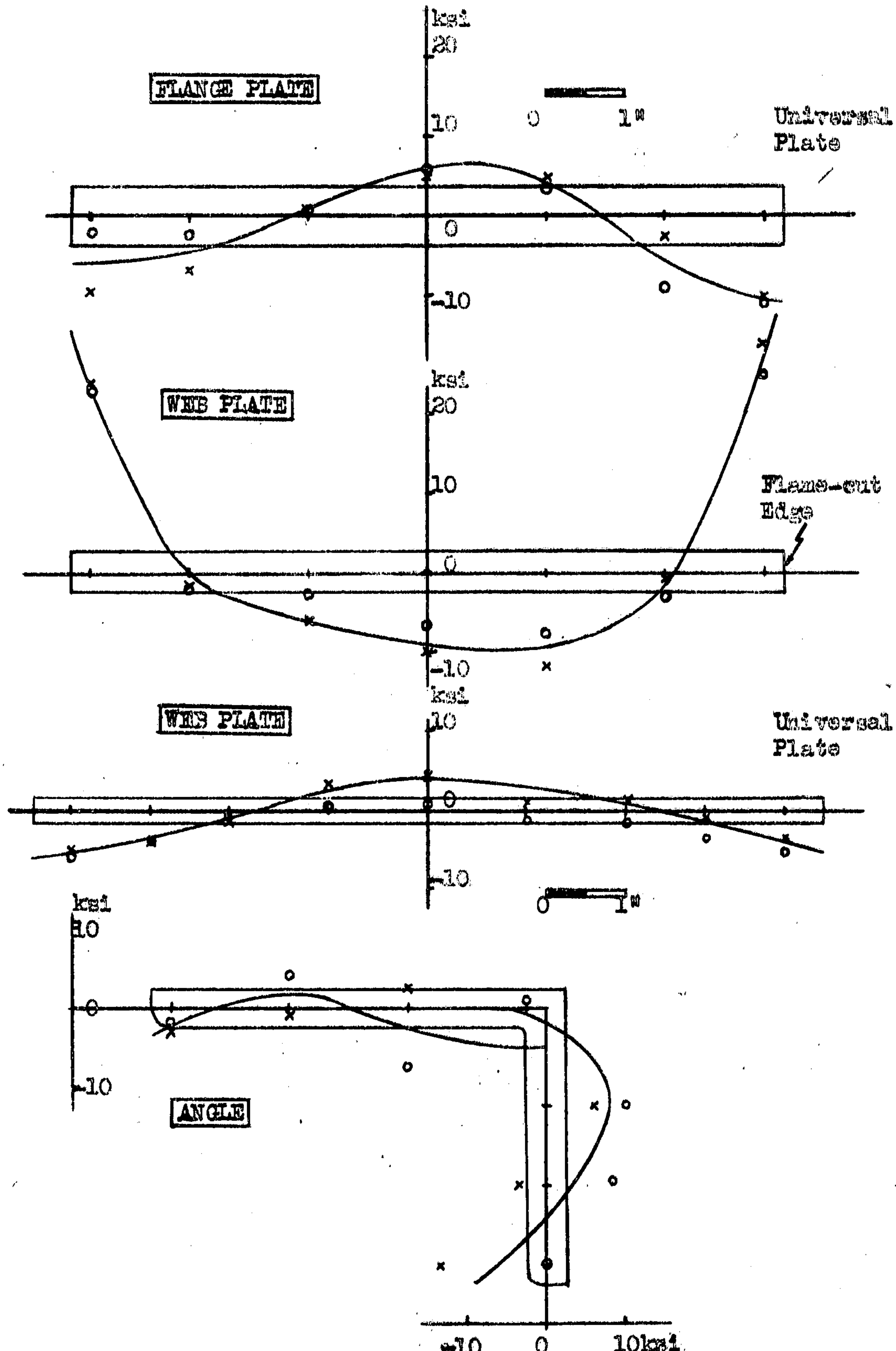
The most valuable suggestions of Dr. Lynn S. Beedle are sincerely appreciated.

The help of Mr. Tadahiko Kawai is gratefully acknowledged, and acknowledgment is also due to Mr. Kenneth R. Harpel, Foreman, who, with his mechanics and technicians, prepared the test setups and specimens.

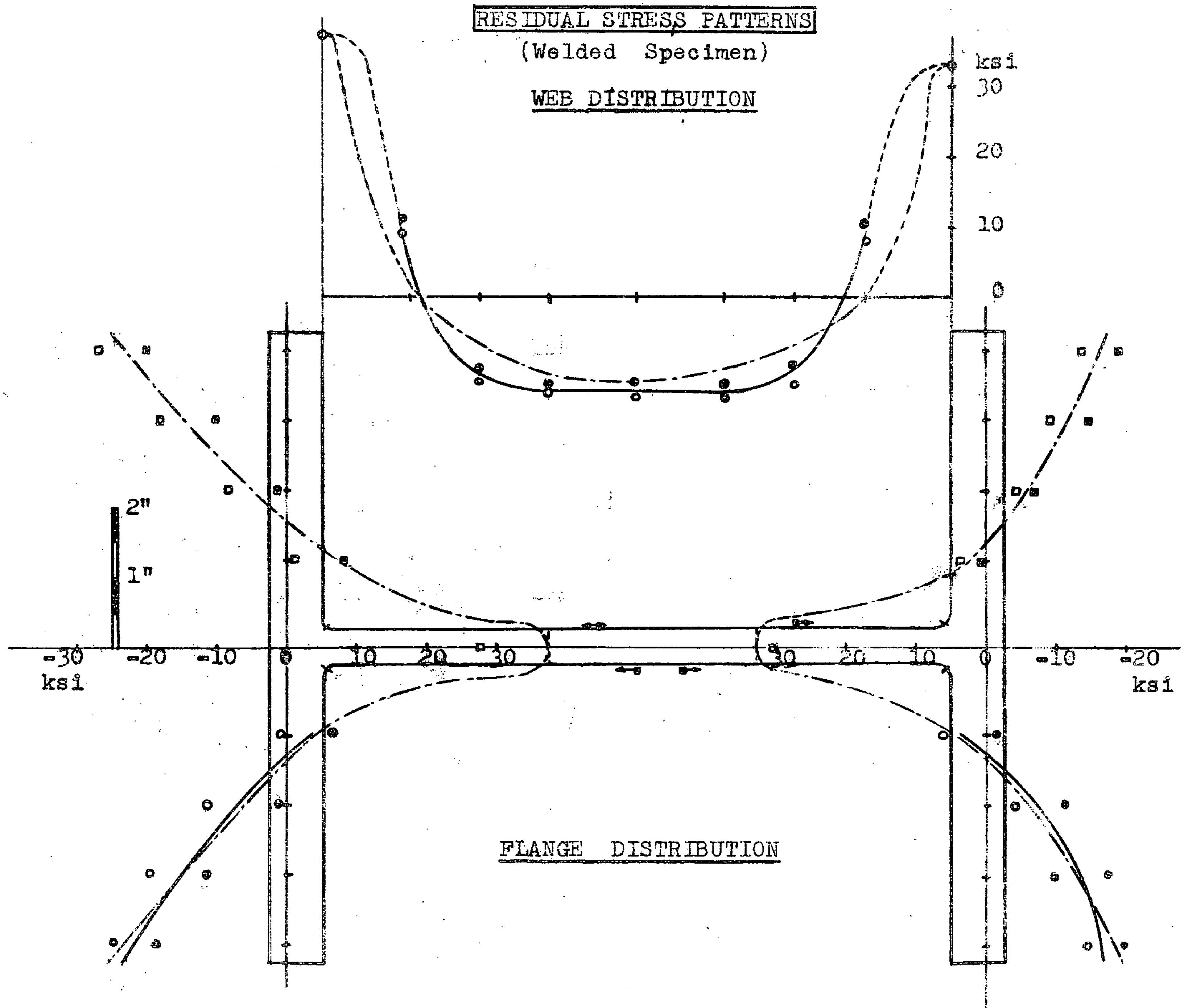
The project on COMPRESSION PROPERTIES OF BUILT-UP COLUMNS, of which this report is a part, is being directed by Dr. Lynn S. Beedle.

TABLE : BUILT-UP COLUMN PROGRAM

Item	Kind	Shape	Area in^2	I_y in^4	I_x in^4	r in: r_{st}	r in: r_{weak}	Cou-pons	Residual Stress	Cross Section	Columns No.	Columns L/r	Note
1	Riveted Specimen	 Web: 10x5/16 Angle: 5x3-1/2 x1/2 (A-7 Steel)	19.13	92.8	344.0	4.23	2.20	6	3	3	2 1	80) 60) 80	Weak Axis Strong Axis
2	Welded Specimen	 Web: 9 x 1/2 Flange: 9 x 3/4 (A-7 Steel)	18.0	91.3	352.0	4.42	2.25	6	3	2	2 1	80) 60) 80	Weak Axis Strong Axis



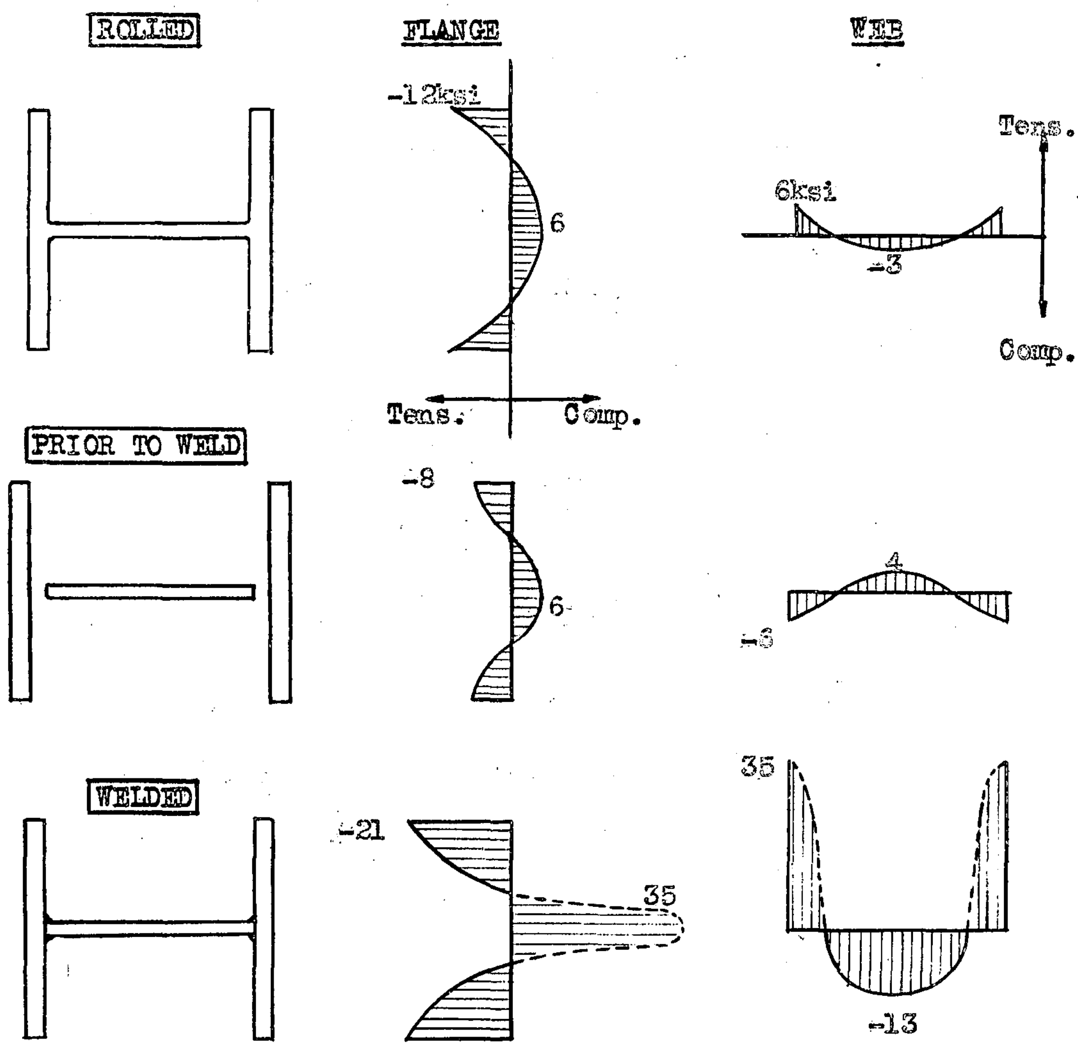
FLANGE PLATE
ksi
20
10
0
-10
0
1"
Universal Plate
WEB PLATE
ksi
20
10
0
-10
Flame-cut Edge
WEB PLATE
ksi
10
0
-10
Universal Plate
0
1"
ANGLE
ksi
10
0
-10
-10
0
10ksi

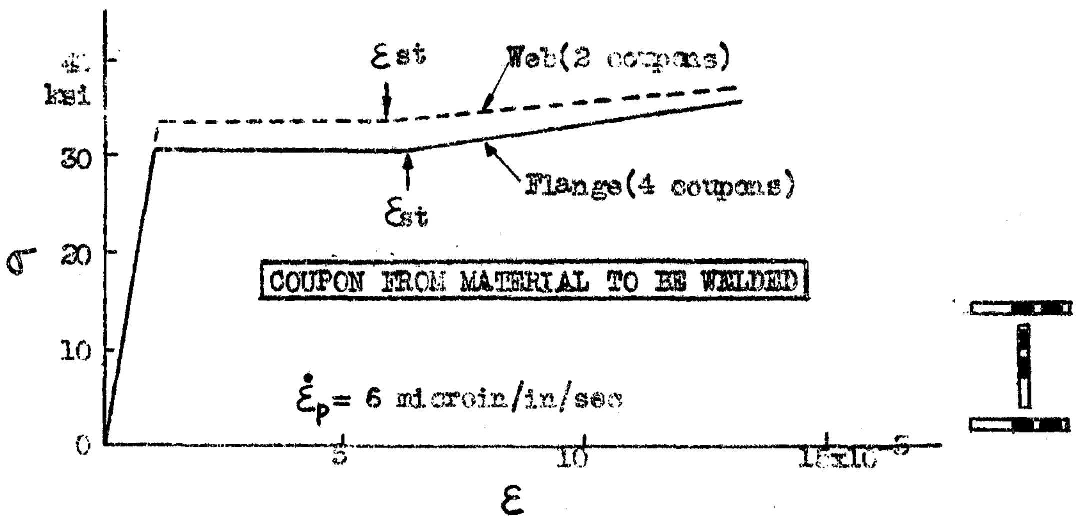


RESIDUAL STRESS PATTERNS
(Welded Specimen)
WEB DISTRIBUTION
ksi
30
20
10
0
2"
1"
-30
-20
-10
0
10
20
30
ksi
FLANGE DISTRIBUTION

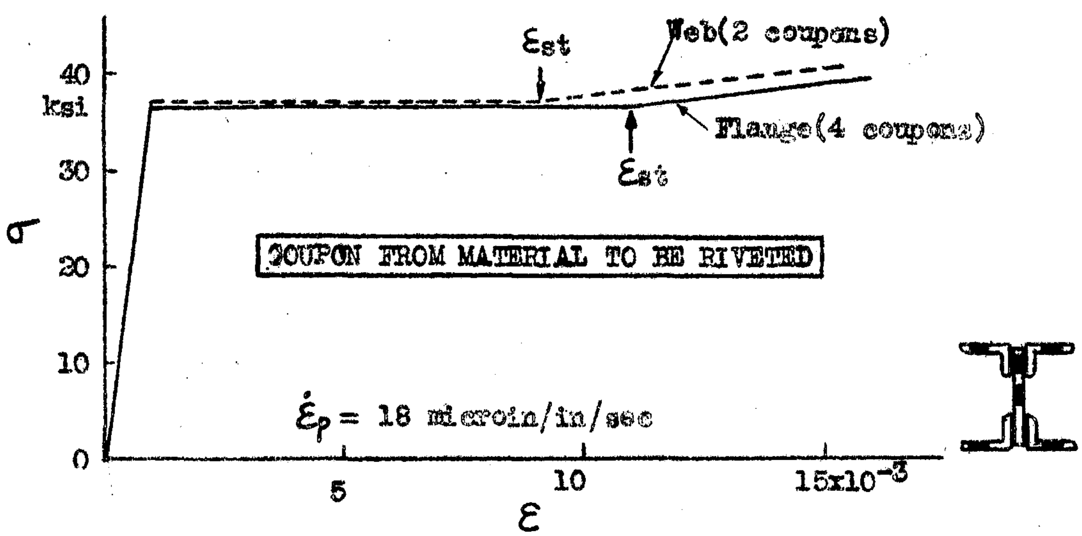
2

RESIDUAL STRESS PATTERNS

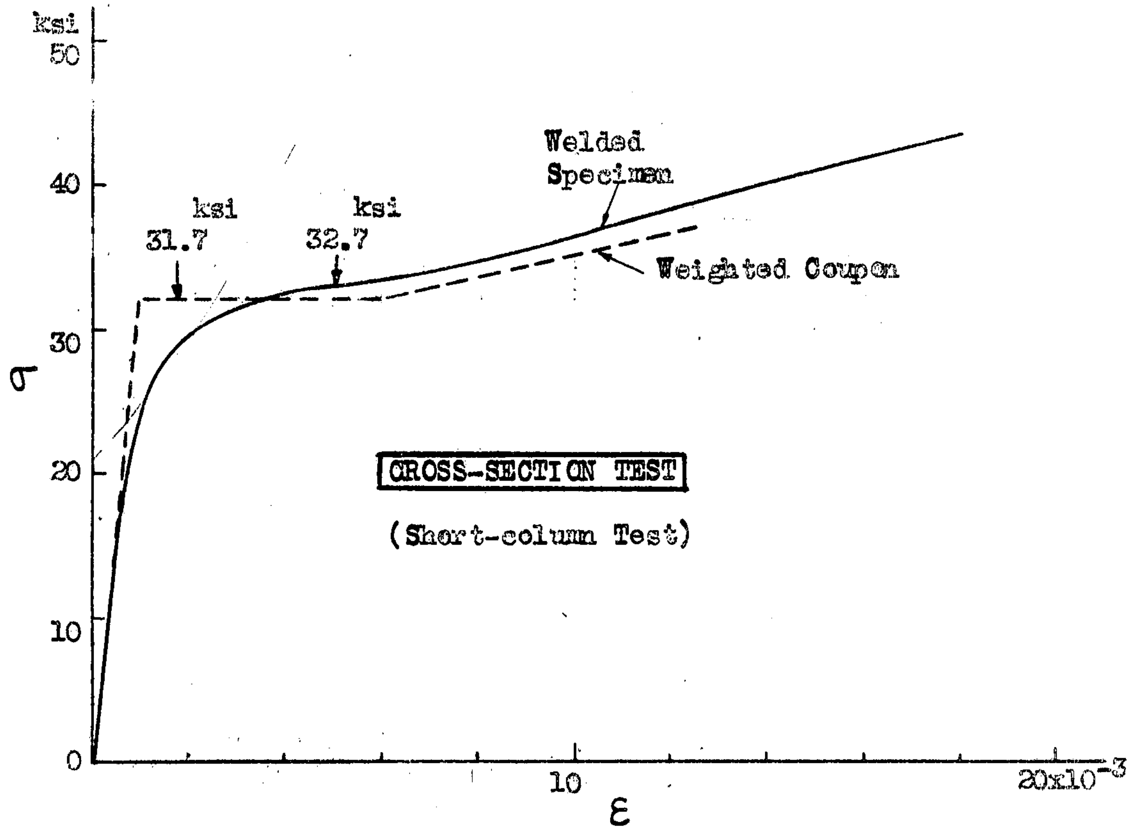




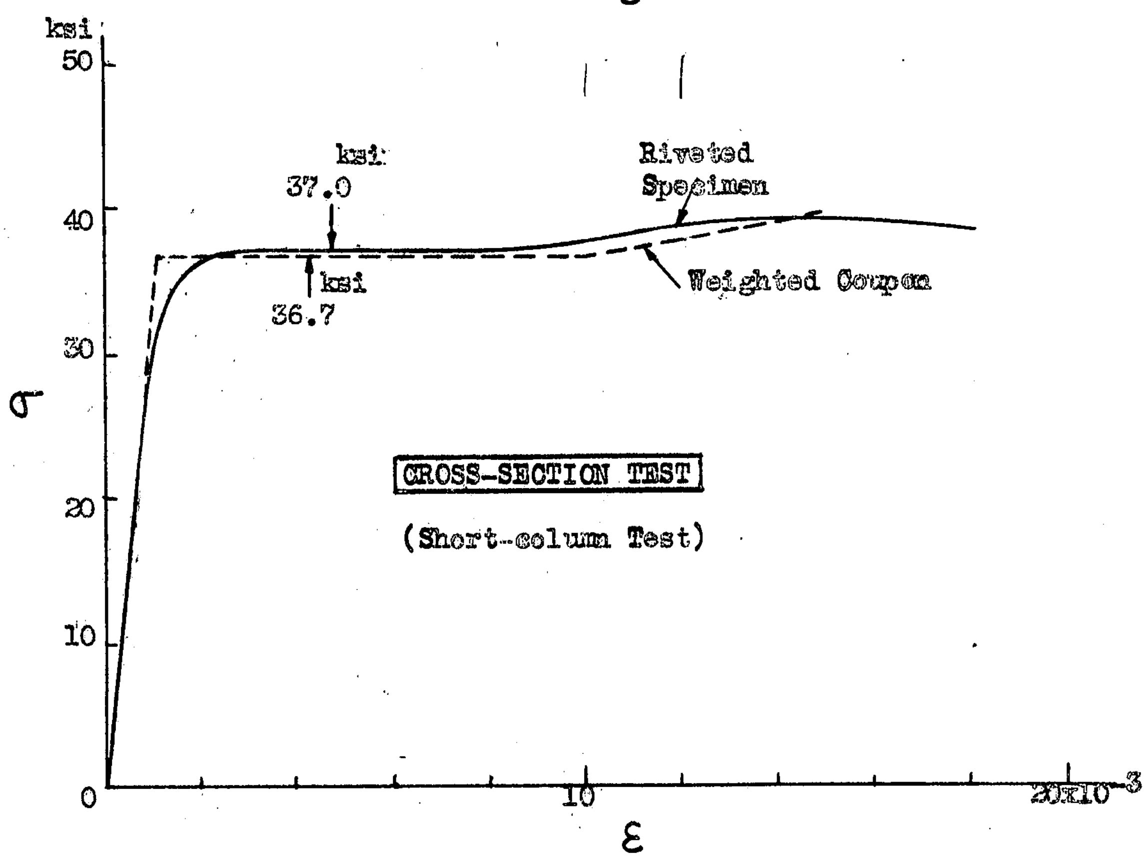
ε_{st}
Web(2 coupons)
ksi
30
20
10
0
σ
ε_{st}
Flange(4 coupons)
COUPON FROM MATERIAL TO BE WELDED
$\dot{\varepsilon}_p$ = 6 microin/in/sec
5
10
15x10^{-3}
ε



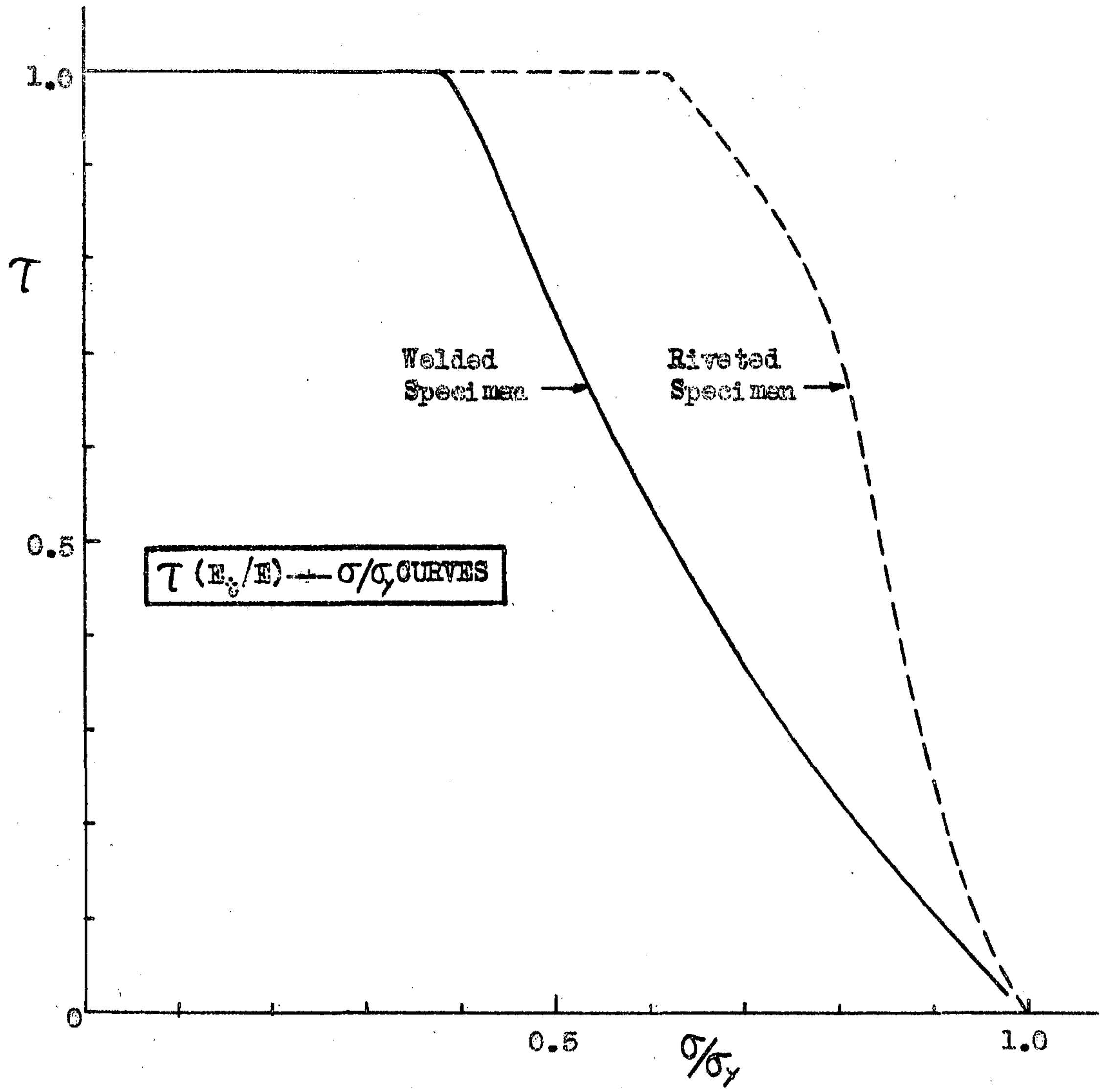
ε_{st}
Web(2 coupons)
40
ksi
30
20
10
0
σ
Flange(4 coupons)
ε_{st}
COUPON FROM MATERIAL TO BE RIVETED
$\dot{\varepsilon}_p$ = 18 microin/in/sec
5
10
15x10^{-3}
ε

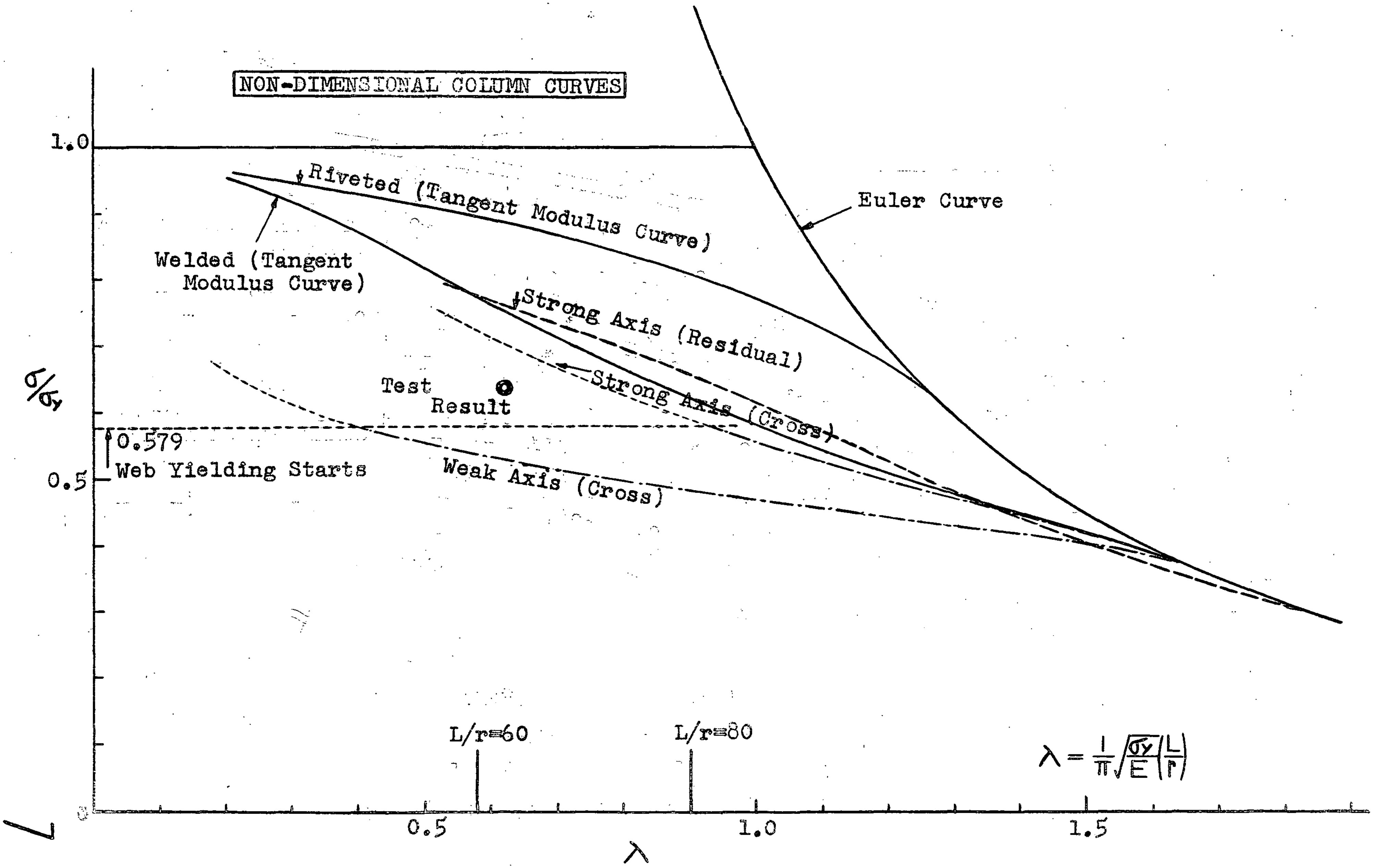


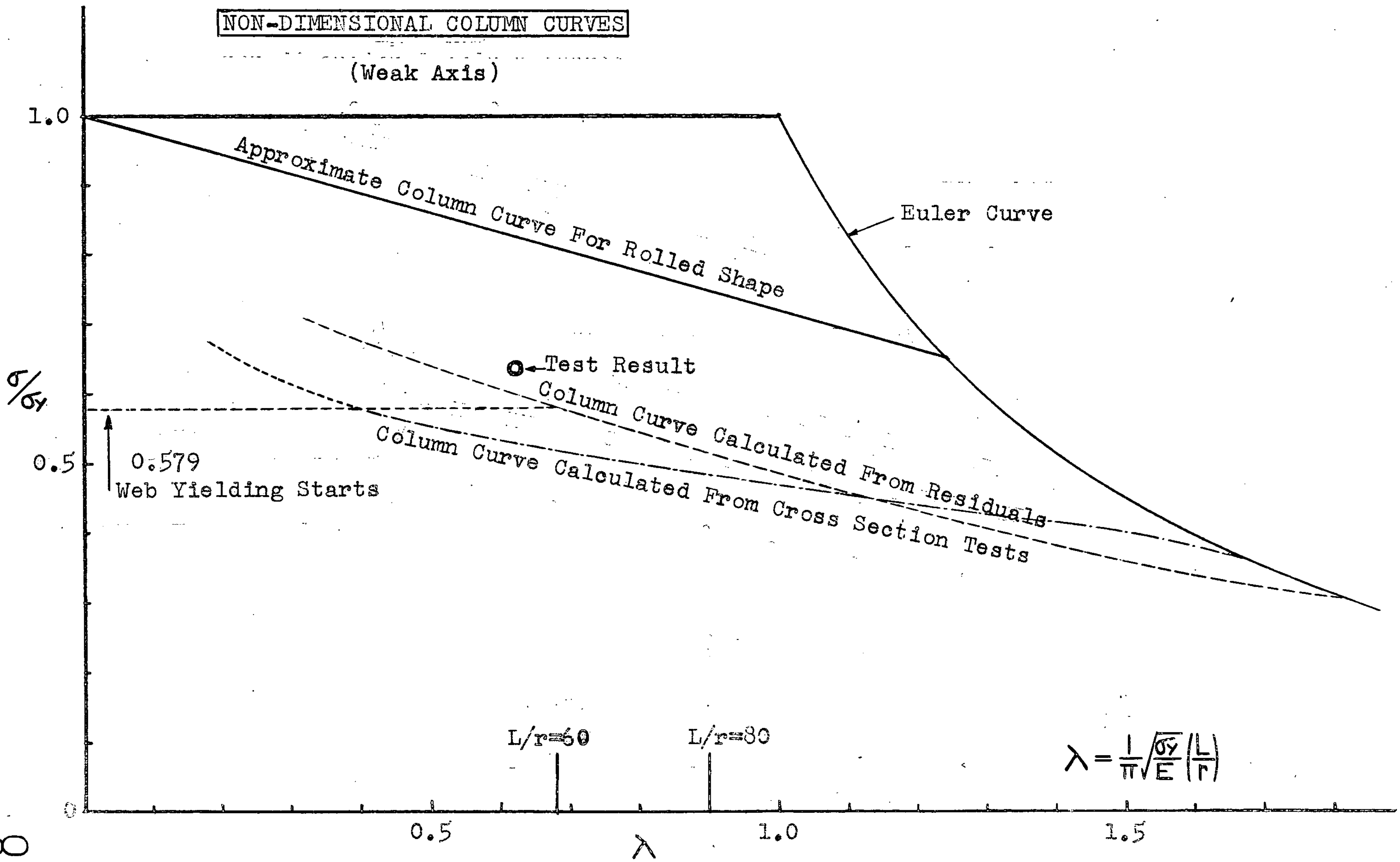
ksi
50
40
30
20
10
0
σ
ksi
31.7
ksi
32.7
Welded
Specimen
Weighted Coupon
CROSS-SECTION TEST
(Short-column Test)
10
20x10^-3
ε



ksi
50
40
30
20
10
0
σ
ksi
37.0
ksi
36.7
Riveted
Specimen
Weighted Coupon
CROSS-SECTION TEST
(Short-column Test)
10
20x10^-3
ε

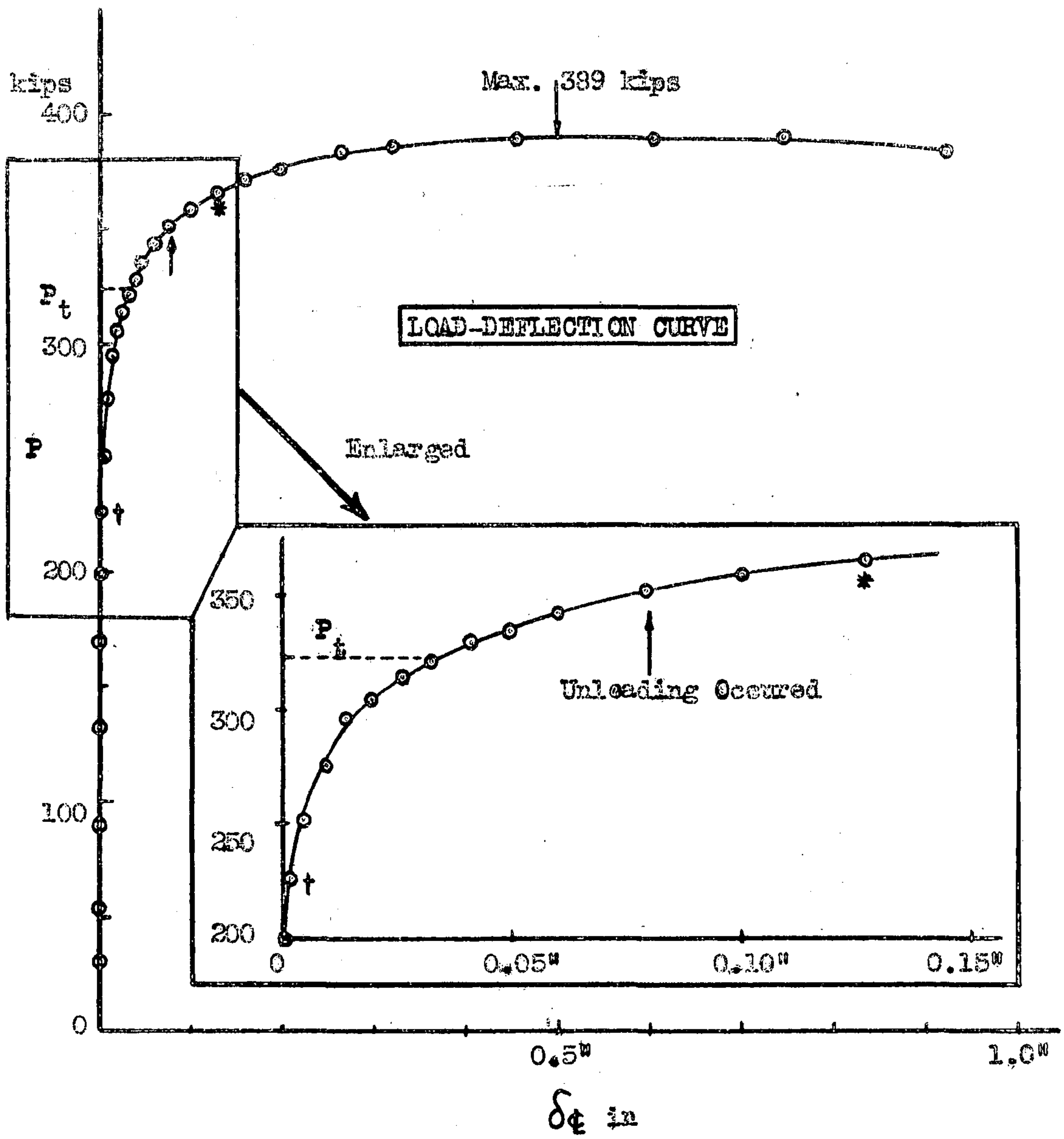

1.0
0.5
0
τ
Welded Specimen
Riveted Specimen
τ (E_t/E) — σ/σ_y CURVES
0.5
1.0
σ/σ_y


NON-DIMENSIONAL COLUMN CURVES
1.0
0.5
σ/σy
Riveted (Tangent Modulus Curve)
Welded (Tangent Modulus Curve)
Euler Curve
Strong Axis (Residual)
Strong Axis (Cross)
Test Result
0.579
Web Yielding Starts
Weak Axis (Cross)
L/r=60
L/r=80
$\lambda = \frac{1}{\pi}\sqrt{\frac{\sigma_y}{E}}\left(\frac{L}{r}\right)$
0
0.5
1.0
1.5
λ



NON-DIMENSIONAL COLUMN CURVES
(Weak Axis)
1.0
0.5
0
σ/σ_Y
Approximate Column Curve For Rolled Shape
Euler Curve
Test Result
Column Curve Calculated From Residuals
Column Curve Calculated From Cross Section Tests
0.579
Web Yielding Starts
L/r=60
L/r=80
$\lambda = \frac{1}{\pi}\sqrt{\frac{\sigma_Y}{E}}\left(\frac{L}{r}\right)$
0.5
1.0
1.5
λ

8


kips
400
300
200
100
0
Max. 389 kips
P_t
P
LOAD-DEFLECTION CURVE
Enlarged
350
300
250
200
0
0.05"
0.10"
0.15"
Unloading Occured
0.5"
1.0"
$\delta_{\mathbb{C}}$ in